DOCUMENT RESUME

ED 429 848	SE 062 552

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TITLE A Comparison of Calculator Use in Eighth-Grade Mathematics Classrooms in the United States, Japan, and Portugal: Results from the Third International Mathematics and Science Study.

PUB DATE 1999-04-00

NOTE 39p.; Paper presented at the Annual Meeting of the American Educational Research Association (Montreal, Canada, April 19-23, 1999).

PUB TYPE Reports - Research (143) -- Speeches/Meeting Papers (150)

EDRS PRICE MF01/PC02 Plus Postage.

DESCRIPTORS *Calculators; Comparative Education; *Cross Cultural Studies; Educational Technology; Foreign Countries; *Grade 8; Junior High Schools; Mathematics Instruction; *National Competency Tests

IDENTIFIERS Japan; Portugal; *Third International Mathematics and Science Study; United States

ABSTRACT

This study used data from the Third International Mathematics and Science Study (TIMSS) to determine trends in calculator use among Population 2 (13-year-olds) students in Japan, the United States, and Portugal. While relatively high levels of calculator use were observed for the U.S. and Portugal, virtually no calculator use was found in the Japanese sample. Hierarchical Linear Model analysis determined a significant negative relationship between students' frequency of calculator use and student performance in Japan. No significant relationship was detected for the U.S. and Portuguese samples. U.S. student achievement was positively associated with each of the five reported ways in which calculators are used; however, a significant negative relationship was found between student performance and Japanese students' use of calculators on tests. Plausible explanations are explored. Contains 18 references. (Author/NB)

A COMPARISON OF CALCULATOR USE IN EIGHTH-GRADE MATHEMATICS CLASSROOMS IN THE UNITED STATES, JAPAN, AND PORTUGAL: RESULTS FROM THE THIRD INTERNATIONAL MATHEMATICS AND SCIENCE STUDY

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A paper presented at the American Educational Research Association Annual Meeting, April 21, 1999, Montreal, Canada.

Abstract

The study used data from the Third International Mathematics and Science Study (TIMSS) to determine trends in calculator use among Population 2 (13-year-olds) students in Japan, the United States, and Portugal. While relatively-high levels of calculator use were observed for the U.S. and Portugal, virtually no calculator use was found for the Japanese sample. Hierarchical Linear Model analysis determined a significant negative relationship between students' frequency of calculator use and student performance in Japan; no significant relationship was detected for the U.S. and Portuguese samples. U.S. student achievement was positively associated with each of the five reported ways in which calculators are used, however a significant negative relationship was found between student performance and Japanese students' use of calculators on tests. Plausible explanations are explored.

A Comparison of Calculator Use in Eighth-Grade Mathematics Classrooms in the United States, Japan, and Portugal: Results From the Third International Mathematics and Science Study

The Third International Mathematics and Science Study (TIMSS), conducted in 1994-1995, undertook to survey international school children and their teachers to determine the scope of several questions concerning educators. Among these questions were (1) the role of technology in teaching and learning mathematics and science, and (2) international variation in mathematics and science curricula. Three populations of students and their teachers were surveyed in 46 educational systems internationally. The subgroups of testing focused on 9 year-olds (Population 1), 13 year-olds (Population 2), and students in the last year of secondary school (Population 3). Data from these groups correspond to grades 4, 8, and 12 in most educational systems. The focus of research in this study was on Population 2 for two reasons: The researchers were highly interested in the use of technology by middle school mathematics students, and in the practices of their mathematics teachers.

Background

Recommendations of the National Council of Teachers of Mathematics

In recent years, the advent of calculator technology has influenced the teaching of mathematics in a profound way in the United States (Demana & Waits, Dunham & Dick, 1994; 1990; Fey & Good, 1985). The National Council of Teachers of Mathematics (NCTM) Curriculum and Evaluation Standards for School Mathematics (1989) has advocated that all students have access to calculators at all times and at all levels. The document includes the following comments concerning calculators:

- The new technology not only made calculations and graphing easier; it has changed the very nature of the problems important to mathematics and the methods mathematicians use to investigate them;

- Calculators and computers for users of mathematics, like word processors for writers, are tools that simplify, but do not accomplish the work at hand;
- The availability of calculators does not eliminate the need for students to learn algorithms. (NCTM, 1989, pg. 8)

From the Professional Standards for Teaching Mathematics (NCTM, 1991, p. 1), The Council recommends that teachers become more proficient in "using, and helping students use technology and other tools to pursue mathematical investigations." The document (NCTM, 1991, p. 134) also states: "Technology changes the nature and emphasis of the content of mathematics as well as the pedagogical strategies used to teach mathematics. With the introduction of technology, it is possible to de-emphasize algorithmic skills; the resulting void may be filled by an increased emphasis on the development of mathematical concepts." Notwithstanding the recommendations of the National Council of Teachers of Mathematics, the degree to which the Standards documents have been implemented has largely been undocumented.

Research on Calculator Use

There are several research findings which document the benefits of calculator use in the classroom. Campbell and Stewart (1993) found that calculators aid in problem solving, number sense, and understanding of arithmetic operations. Student confidence, enthusiasm and self-concept at all levels were increased by calculator usage (Campbell & Stewart, 1993; Hembree & Dessart, 1986). Suydam (1987) noted that over 100 studies reported that the use of calculators (a) promotes achievement, (b) improves problem-solving skills, and (c) increases understanding of mathematical ideas. Hembree and Dessart (1986) gathered information from 79 research reports and found that at every grade level from kindergarten through 12 (except Grade 4) that the use of calculators can improve the average student's paper-and-pencil skills, both in basic operations and in problem solving. Suydam (1982) reported that no evidence had been found that elementary students become calculator dependent. Dunham (1993) found that nearly always, students taught with calculators (but tested without technology) had computation achievement scores as high or higher than those taught without technology. More recently, Dunham (1996) reported results from

14 dissertations, five journal articles, and seven conference papers; she found research continuing to show positive results or no significant difference for technology users in the classroom.

Purpose of the Study

Since the aforementioned research findings indicate positive results for calculators usage, the authors of the present study sought to investigate the major trends and perceived use of calculators by middle school students. The study used TIMSS data on calculator usage for Population 2 collected from both students and their teachers to ascertain how often calculators are used and the ways in which they are used. The present study reports the major trends in calculator use in Japan, United States and Portugal and relates calculator use to students' mathematics achievement on TIMSS.

Methodology

The process of estimating each country's score from the sample of students who participated in TIMSS produced only an estimate of the nation's real score. This margin of error is expressed as an interval around each country's estimated score. Because the precise score cannot be determined with perfect accuracy, nations were grouped into broad bands according to whether their performance was significantly higher than, not significantly different than, or significantly lower than the U.S.. Table 1 represents Nations' Average Mathematics Performance Score Compared to the U.S..

(Insert Table 1 About Here)

Selection of Nations

In order to make international comparisons on students' calculator use, Japan was selected from the group of 20 nations scoring significantly higher than the U.S., and Portugal was selected from the group of seven nations scoring significantly lower than the U.S.. Japan was chosen for its tradition of excellence in mathematics achievement, and because it was the only country from the set of nations scoring significantly higher than the U.S. for which qualitative data was available. Portugal, a European nation, was chosen after several of the nations scoring significantly lower than the U.S. failed to meet international guidelines for TIMSS, and one other nation from the group excluded more than 10% of its population from testing.

Data Analysis

This study sought to ascertain to what degree calculator use is associated with American, Portuguese and Japanese eighth graders' mathematics score on TIMSS. As a statistical method, classical approaches, such as OLS, were avoided because typical education data has a complicated sample design that often violates the assumption of independence, namely, that sampled cases are independently drawn from the population. In TIMSS, students from the same mathematics classroom are sampled from each school. Because students in each school attend the school for the similar reasons and because they share the similar experiences, the cases that are sampled from the same schools are not independent from each other, leading to the cluster effect problem and underestimation of standard errors.

Hierarchical Linear Model analysis (HLM) (Bryk, & Raudenbush, 1992) avoids the cluster effect problem by incorporating into the model a unique random effect for the group unit in which individuals are nested. In this application, Level 1 represents students and Level 2 represents schools. Intuitively, HLM executes a regression in each school and determines a set of coefficients that vary across group units. For example, schools have different intercepts; likewise, other coefficients that express association between predictors and the dependent variable also may vary across group units. These randomly varying Level 1 coefficients become outcomes at Level 2, which are then modeled by Level 2 predictors. Thus, HLM yields a decomposition of total variance into variances specific to the student and school levels. In this application, only the intercept will be set random because there were no expectations as to how the independent variables would vary across schools. See Appendix A for detailed specifications of HLM models employed in this application.

Variables

Appendix B lists all the variables employed in the HLM analysis. The dependent variable was each nation's average mathematics score, which were prepared to be internationally comparable. Because every student was not tested on the same items, the Item Response Theory (IRT) was employed to estimate a range of plausible values, rather than one single score. Five plausible values were used in this analysis; they contain not only the information about a student's proficiency but also the uncertainty or measurement imprecision that come with the measurement. Five regression models were run for each plausible value and from the five sets of estimates, the average was taken as the final result.

One student-level independent variable, CALCLASS, was students' reports of frequency of calculator use during mathematics lessons. Student responses ranged from 0 (rare) to 3 (almost always). A second set of variables came from teacher surveys. Teachers were asked, "How often do students in your mathematics class use calculators for the following activities? Checking answers; Tests and exams; Routine computation; Solving complex problems; Exploring number concepts." Teachers' responses were recoded to range from 0 (never) to 3 (almost every day). This set of five variables (CHECK, ROUTINE, TEST, SOLVE, and EXPLORE) from teacher surveys were entered into the HLM model at Level 2 because they represent characteristics of teachers rather than students (see Appendix A, note 3). Control variables included student's gender, their use of extra instructions outside classrooms, their expected educational level to complete, and the types of communities that the schools were located.

Limitations

Ideally, there were certainly other important variables that should have been incorporated into the analysis. However, because the Japanese sample lacked students' private information, controls for home environment or ethnicity were not considered here. Even when the information was available for the U.S. and Portugal, it was not included so that the three nations could be contrasted using the same set of variables. Exclusion of such variables may be a source of model misspecification, and this is recognized as a possible weakness of the study.

Results

This section is organized into two parts. First, descriptive statistics on calculator use is offered for each nation; data from student surveys precedes data from teacher surveys. Second, results of the HLM analysis are disclosed. More specifically, the regression analysis attempts to link student performance to frequency of calculator use and the ways in which it was used. The section concludes with a summary of research findings.

Descriptive Analysis of Calculator Use

Students' reports on frequency of calculator use. Students' use of calculators in mathematics lessons varied substantially by nation. As depicted in Table 2, nearly 68% of U.S. eighth-grade students reported they use calculators "almost always" or "pretty often." A nearly identical portion, 69%, of Population 2 students in Portugal reported such regular calculator use. By way of contrast, calculator use among Japan's eighth-grade students was profoundly low. In particular, less than 4% of Population 2 students reported they use calculators "almost always" or "pretty often," and nearly three out of four Japanese students indicated they "never" use calculators during mathematics lessons. Of all nation's participating in TIMSS, only Korea's Population 2 students reported less calculator use during instruction (Beaton, Mullis, Martin, Gonzalez, Kelly, & Smith, 1996).

(Insert Table 2 about here)

Teachers' reports on ways in which students' use calculators. An analysis of teachers' responses to questions on calculator usage in Population 2 classrooms revealed distinctive trends across the three nations. With respect to U.S. classrooms, regular use of calculators during instruction was reported by Population 2 teachers. As depicted in Table 3, U.S. students most commonly utilized calculators to solve complex problems (2.17) and to perform routine computations (1.96). Other reported uses of the calculator included exploring number concepts (1.71), and checking answers (1.52). Of the five reported ways in which calculators are used, American students were least likely to use calculators during tests and exams, although the mean response of 1.42 suggests that many students are given access to such technology during test conditions.

With respect to Portuguese students, calculator use was not statistically different than in U.S. mathematics classrooms. As shown in Table 3, Portuguese students most commonly used calculators to check answers (2.20) and to perform routine computations (2.12). They were somewhat less likely to use calculators to solve complex problems (1.89) and to explore number concepts (1.63) and like their American counterparts, they were least likely (1.40) to use calculators during testing conditions.

(Insert Table 3 about here)

Calculator use in Japan's Population 2 classrooms was markedly different than both the U.S. and Portugal. As shown in Table 3, Japanese teachers reported little or no calculator use by students in each of the five aforementioned ways. A chi-square analysis determined that each of the five means was significantly higher ($p < .0001$) than the corresponding mean for the U.S., and the same was true with respect to Portugal. In essence, with means ranging from 0.09 to 0.16, Japanese teachers indicate negligible use of calculators in eighth-grade mathematics and this is particularly true during test conditions.

Results of the HLM Analysis

Relating frequency of calculator use to student performance. In order to model the effect of predictors such as calculator use, it is necessary to first establish the presence of substantial variation in the outcome variable, namely student performance. In Tables 4a-c, Model 1 is an analysis-of-variance model with no predictor. The intercept represents each nation's average achievement score around which variation within and between schools is observed. The American sample showed a large proportion of variance between schools (36%), while for the Portuguese and Japanese samples, it was relatively small, 14% and 8%, respectively (see Appendix A, note

4). This result implies that the school-level effect of calculator use will be harder to be detected in the Portuguese and Japanese samples than the American sample because there was not much level-2 variation to model in the first place.

In Model 4, the key variable, students' reported use of calculator during instruction, was considered at Level 1. As depicted in Table 4, the U.S. model suggests that the direction of effect was positive but not significant and the Portugal model shows the opposite, a negative effect that was not significant. The Japanese model, however, shows clear significance ($p < .001$) and it was highly negative. In particular, a one unit increase in students' reported use of calculators during instruction was associated with a 21-point decrease in student performance scores. The reduction of Level 1 variance was 1.4% when compared with a base Model 3 (see Appendix A note 5 for comparison of variance across models). This small reduction in variance makes sense because Japanese students report that they rarely use calculators in classrooms.

(Insert Tables 4a, 4b, and 4c about here)

Relating ways in which calculators are used to student performance. In Tables 5a-c, Model 5 to Model 9 concern the uses of calculators for checking answers (CHECK), tests and exams (TEST), routine computations (ROUTINE), solving complex problems (SOLVE), and exploring number concepts (EXPLORE). As represented in Tables 5a-c, most of the large effects came from the U.S. sample. More specifically, each of the five reported ways in which calculators are used by American students was strongly associated ($p < .001$) with student achievement. Each one unit increase in the use of calculators to check answers resulted in a 15.3-point increase in student performance; each incremental increase in calculator use on tests and exams was associated with a 14.7-point increase, and an 11.2-point increase was observed as calculator use to perform routine computations increased incrementally. Even greater coefficients were determined for calculator use to solve complex problems and to explore number concepts, with a 20.1-point and 18.4-point increase in performance, respectively. The reduction of Level 2 variance compared with an earlier model, Model 3, was substantial. The most reduction of Level 2 variance was observed with Model 8 (17%) and the least reduction was found with Model 7 (6%), the latter of which was still large.

(Insert Tables 5a, 5b, and 5c about here)

In contrast, Japanese and Portuguese teachers' reports on ways in which calculators are used were not strongly associated with achievement. One particular item, TEST, from the Japanese sample a showed strong negative effect. More precisely, for each one unit increase in this variable, there was a 20-point reduction in the school's average test score. However, Level 2 variance reduction compared to Model 3 was negligible. Other items showed no significance; such a result is understandable given that calculators are rarely used in Japanese mathematics classrooms. Further, as Model 1 suggested, there was not much variance at school-levels, hence, it was expected that Level 2 predictors would not show strong association with the outcome variables. The same applies to Portugal's sample. No significant coefficient for calculator use was observed in the case of Portugal.

Summary of Research Findings

Students' reports on frequency of calculator use was positively related with achievement in the U.S. but the coefficient size was not significantly large. It was associated negatively in Portugal's sample, but only insignificantly. Only for the Japanese sample was a significant negative coefficient observed. With respect to teachers' reported ways in which calculators are used (checking answers, test/exams, performing routine computations, solving complex problems, and exploring number concepts), the American sample showed significantly large positive coefficients in all items. By way of contrast, the Japanese sample showed a significantly negative relationship only between student performance and their use of calculators on tests. No relationship between calculator use and student performance was detected in Portugal's sample.

Discussion

Data from both student and teacher surveys confirm that calculator use in eighth-grade classrooms varies substantially across nations. Perhaps most intriguing is the virtual absence of calculator use in Japanese eighth-grade mathematics classrooms, particularly given Japan's technologically-advanced society and its tradition of excellence in mathematics education. Moreover, this key research finding is even more remarkable when considering the ever-expanding body of research (e. g., Campbell & Stewart, 1993; Hembree & Dessart, 1986; Suydam, 1987) documenting the benefits of calculator use in fostering students' understanding of mathematical ideas.

A second important finding is the relatively-high degree of calculator use by U.S. eighth-grade students. Whether or not American mathematics teachers are cognizant of standards calling for the provision of calculator technology, the results of this study suggest that most students have access such technology during instruction and under testing conditions. Indeed, only 10% of U.S. students comprising Population 2 indicated that they "never" use a calculator during mathematics lessons.

In addition having access to calculators during instruction, results indicate that U.S. students are afforded opportunities to use calculators in nonroutine ways, including the exploration of number concepts and solving complex problems. It is interesting to note how U.S. student achievement was related to specific calculator uses during instruction. Activities that stress higher-order mentality, arguably to solve complex problems (SOLVE) and to explore number concepts (EXPLORE), showed the largest effect size, while more practical activities -- to check answers (CHECK), on tests and exams (TEST), and to perform routine computations (ROUTINE) -- showed smaller effect size. These results suggest that in the U.S. the positive effect of calculator use is particularly salient with activities that require higher-order thinking. Moreover, such results lend credence to the notion that calculators can foster students' understanding of mathematical ideas.

The stark contrast in technology practices in Japan and the United States precipitates a search for possible explanations. That is, what factor(s) would preclude Japanese eighth-grade students from using a calculator during instruction or on mathematics exams?

Discounting Curricular Differences

It may seem plausible to attribute the minimal use of calculators in Japan to its mathematics curricula; that is, one may conjecture that Japanese eighth-graders are studying mathematics content that simply does not lend itself to hand-held calculators. If geometric concepts, for example, are the focus of study in eighth-grade, then Japanese students may find little or no use for such technology. But is calculator use in Japan and the U.S. attibutable curricular differences? Examination of each nation's mathematics curriculum for eighth-grade students may yield answers. One caveat, however, is warranted. To determine the effect of particular curricular activities on student achievement, longitudinal data is needed, but not offered by TIMSS. Moreover, curriculum data from TIMSS was not available at press time. Notwithstanding this lack of data, it is possible to surmise Japan's implemented curriculum by examining its intended curriculum.

Japan and Portugal represent two of the 29 nations in TIMSS whose mathematics curriculum is set at the national level. In Japan, the National Ministry of Education specifies one set of curriculum guidelines that specifies the number of instructional hours for each mathematics topic, and approves textbooks published by six commercial publishers. The national mathematics curriculum in Japan is focused. In particular, only three objectives for eighth-grade students are identified:

1) To help students develop their abilities to compute and transform algebraic expressions using letter symbols according to their purposes, and to help them understand linear inequalities and simultaneous equations, and to foster their abilities to use them.
2) To help students deepen their understanding of the properties of the fundamental figures in a plane, and thereby understand the significance and methods of mathematical inference with reference to consideration of the properties of figures, and to foster their abilities to precisely represent the process of inference.

3) To help students further deepen the way of viewing and thinking variation and correspondence and understand the characteristics of linear functions, and foster their abilities to use them. Furthermore, to help students adequately represent numbers according to their purposes and develop their abilities to grasp the tendencies of statistical phenomena.

Although Japan's integrated mathematics curriculum does devote some degree of attention to geometry, it also focuses heavily on algebraic concepts as well as on statistical and algebraic reasoning, all of which provide abundant opportunities for calculator use. Consequently, the minimal use of calculators in Japan does not appear to be related to its mathematics curriculum.

In contrast to Japan and Portugal, the U.S. mathematics curriculum is determined at local levels and often follows broad guidelines as set by each of the 50 states. Because the mathematics curriculum is not similar among or even within the educational systems surveyed, it is difficult to get a clear sense of a typical eighth-grade mathematics curriculum, particularly since only 28% of U.S. students use one of the five most-commonly used textbooks. Nevertheless, national recommendations (NCTM, 1989), on which state frameworks and local school district guidelines are largely based, place increased emphasis on developing number sense, identifying and using functional relationships, using statistical methods, and using appropriate technology for computation and exploration. Such recommendations represent a departure from curricular practices of the 1980's when the U.S. junior high school curriculum was primarily devoted to developing students' computational skills (McKnight, Crosswhite, Dossey, Kifer, Swafford, Travers, & Cooney, 1987). Whether U.S. students are subjected to a reform-based mathematics curriculum or one that is more arithmetic-latent, their curriculum affords them numerous opportunities to use calculators during instruction.

Cultural Differences

Because differences in American and Japanese technology practices do not appear to be a related to their respective mathematics curricula, alternative explanations must be sought. Are such polar educational practices more attributable to cultural differences? In Japan, educators and students may not be enthusiastic about the use of calculator. A principle reason for this is that an important emphasis of education in Japanese junior high schools is preparation for the high school entrance examination. In this examination, the use of calculators is not allowed; thus, in preparing students for this exam, teachers may put a stress on a student's ability to perform mathematical operations without the use of a calculator. Generally speaking, use of calculators in mathematics classrooms is associated with "cheating."

Further, a general apathy towards the use of technology in education comes from a cultural ethos that downplays technology in Japan. Education is associated with discipline, compliance to the authority, and socialization, rather than creative processes towards the development of individuality and skills (Rohlen, 1983). As a result, the use of both calculator and computer technology may be perceived as a deviation from the cultural ideals of education.

Agenda for Future Research

Results of the present study revealed calculator use and its association with student achievement varies greatly between the nations of Japan, the United States, and Portugal. Although such relationships were ascertained for Population 2, data from Population 1 (9-year-olds) and Population 3 (17-year-olds) remain unexplored. Accordingly, it is the intent of the research team to analyze both teacher and student data from Populations 1 and 3 in order to determine possible links between calculator use and student performance.

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Table 1

Nations Average Mathematics Performance Compared to the United States

NATIONS WITH AVERAGES SIGNIFICANTLY HIGHER THAN THE UNITED STATES		NATIONS WITH AVERAGE SCORES NOT SIGNIFICANTLY DIFFERENT FROM THE UNITED STATES		NATIONS WITH AVERAGE SCORES SIGNIFICANTLY LOWER THAN THE UNITED STATES	
NATION	AVERAGE	NATION	AVERAGE	NATION	AVERAGE
Singapore	643	(Thailand)	522	Lithuania*	477
Korea	607	(Israel)*	522	Cyprus	474
Japan	**605**	(Germany)*•	509	**Portugal**	**454**
Hong Kong	588	New Zealand	508	Iran, Islamic Republic	428
Belgium-Flemish•	565	England	506	(Kuwait)	392
Czech Republic	565	Norway	503	(Colombia)	385
Slovak Repulbic	547	(Denmark)	502	(South Africa)	354
Switzerland•	545	**United States•**	**500**		
(Netherlands)	541	(Scotland)	498		
(Slovenia)	541	Latvia (LSS)•	493		
(Bulgaria)	540	Spain	487		
(Austria)	539	Iceland	487		
France	538	(Greece)	484		
Hungary	537	(Romania)	482		
Russian Federation	535				
(Australia)	530				
Ireland	527				
Canada	527				
(Belgium-French)	526				
Sweden	519				

Notes. Nations not meeting international guidelines are shown in parentheses. Nations in which more than 10 percent of the population was excluded from testing are shown with a *. Latvia is designated LSS because only Latvian-speaking schools were tested, which represents less than 65 percent of the population. Nations in which a participation rate of 75 percent of the schools and students combined was achieved only after replacements for refusals were substituted, are shown with a •. The country average for Sweden may appear to be out of place; however, statistically, its placement is correct.

Table 2

Students' Reports on Frequency of Using Calculators During Mathematics Lessons -- Japan, U.S., and Portugal

	Never		Once in a While		Pretty Often		Almost Always	
Country	Percent of Students	Mean Achieve-ment	Percent of Students	Mean Achieve-ment	Percent of Students	Mean Achieve-ment	Percent of Students	Mean Achieve-ment
Japan	74.7 (2.27)	607.24 (2.06)	20.8 (1.88)	603.04 (3.37)	3.46 (0.65)	575.35 (6.69)	0.37 (0.09)	524.37 (24.12)
U.S.	9.88 (1.52)	463.87 (9.39)	19.62 (1.54)	498.28 (5.83)	24.86 (1.16)	501.22 (5.30)	43.03 (2.66)	510.63 (5.64)
Portugal	3.02 (0.61)	455.29 (7.32)	27.19 (1.59)	456.56 (3.10)	34.07 (1.19)	453.87 (3.50)	34.80 (1.45)	454.08 (2.83)

Note. Standard Errors are reported in parentheses.

Table 3

Teachers' Reports on Ways in Which Calculators are Used in Mathematics Lessons -- Japan, U.S., and Portugal

	Checking Answers	Tests and Exams	Routine Computation	Solving Complex Problems	Exploring Number Concepts
Country	Mean Response	Mean Response	Mean Response	Mean Response	Mean Response
Japan	0.04 (0.02)	0.01 (0.00)	0.14 (0.04)	0.11 (0.03)	0.16 (0.05)
U.S.	1.52 (0.09)	1.42 (0.11)	1.96 (0.11)	2.17 (0.09)	1.71 (0.09)
Portugal	2.20 (0.10)	1.40 (0.08)	2.12 (0.09)	1.89 (0.10)	1.63 (0.09)

Note. Teachers responses were recoded in the following manner: 0 = Never or Hardly Ever, 1 = Once or Twice Per Month, 2 = Once or Twice a Week, 3 = Almost Every Day. Standard Errors are reported in parentheses.

Table 4a

Results of Hierarchical Linear Model Analysis of

Students' Reported Frequency of Calculator Use (CALCLASS) and Student Performance -- U.S.

U.S.	**Model 1**	**Model 2**	**Model 3**	**Model 4**
School-level	Coef. (Std.)	Coef. (Std.)	Coef. (Std.)	Coef. (Std.)
INTERCEPT	491.8 (3.9) ***	489.8 (5.9) ***	489.3 (5.6) ***	489.3 (5.6) ***
Location				
Rural		10.4 (10.8)	12.9 (10.3)	12.9 (10.3)
Suburb		17.3 (9.6)	17.2 (9.2)	17.2 (9.2)
Locmiss		-27.0 (11.3)	-25.5 (10.9) *	-25.4 (10.9) *
Student-level				
CALCLASS				0.3 (1.8)
Girl			-5.7 (2.3) *	-5.7 (2.3) *
Tmjuku			-8.1 (1.5) ***	-8.1 (1.5) ***
SED			5.3 (0.5) ***	5.3 (0.5) ***
LIKEMATH			16.9 (1.2) ***	16.9 (1.2) ***
Level-1 Variance	4227.2	4226.7	3919.6	3919.9
Level 2 Variance	2407.6	2257.0	2081.7	2074.7

Note. Standard Errors are reported in parentheses.

*$p < .05$

**$p < .01$

***$p < .001$

Table 4b

Results of Hierarchical Linear Model Analysis of

Students' Reported Frequency of Calculator Use (CALCLASS) and Student Performance -- Portugal

Portugal	**Model 1**	**Model 2**	**Model 3**	**Model 4**
School-level	Coef. (Std.)	Coef. (Std.)	Coef. (Std.)	Coef. (Std.)
INTERCEPT	454.3 (2.4) ***	455.7 (3.1) ***	456.0 (3.0) ***	455.0 (3.0) ***
Location				
Rural		-10.8 (8.3)	-11.8 (8.0)	-11.5 (8.1)
Suburb		-2.2 (5.7)	-2.9 (5.5)	-3.0 (5.5)
Locmiss		2.4 (9.8)	3.6 (9.4)	1.8 (9.4)
Student-level				
CALCLASS				-2.7 (1.8)
Girl			-11.7 (2.5) ***	-11.7 (2.5) **
Tmjuku			-11.0 (1.8) ***	-11.0 (1.8) **
SED			2.9 (0.5) ***	2.9 (0.5) ***
LIKEMATH			17.0 (1.3) ***	17.0 (1.3) ****
Level-1 Variance	3327.5	3327.5	2966.1	2961.2
Level 2 Variance	577.4	582.4	536.3	541.0

Note. Standard Errors are reported in parentheses.

*$p < .05$

**$p < .01$

***$p < .001$

****$p < .0001$

Table 4c

Results of Hierarchical Linear Model Analysis of

Students' Reported Frequency of Calculator Use (CALCLASS) and Student Performance -- Japan

Japan	**Model 1**	**Model 2**	**Model 3**	**Model 4**
School-level	Coef. (Std.)	Coef. (Std.)	Coef. (Std.)	Coef. (Std.)
INTERCEPT	602.9 (2.8) ***	599.9 (4.6) ***	599.6 (4.3) ***	598.6 (3.9) ***
Location				
Rural		-8.3 (7.4)	-4.2 (6.9)	-1.1 (0.9)
Suburb		11.5 (6.2)	11.0 (5.8)	11.9 (0.0)
Locmiss		12.2 (34.9)	20.2 (32.6)	18.9 (7.3)
Student-level				
CALCLASS				-21.2 (3.1) ***
Girl			1.1 (2.8)	-0.4 (2.8)
Tmjuku			-3.4 (1.4) *	-3.5 (1.4) *
SED			6.0 (0.6) ***	6.0 (0.6) ***
LIKEMATH			32.3 (1.9) ***	31.9 (1.9) ***
Level-1 Variance	9166.1	9166.6	8263.2	8148.8
Level 2 Variance	780.1	735.3	624.6	716.7

Note. Standard Errors are reported in parentheses.

*$p < .05$

**$p < .01$

***$p < .001$

Table 5a

Results of Hierarchical Linear Model Analysis of

Student Performance and Teachers' Reports on Ways in Which Calculators Are Used -- U.S.

U.S.	Model 5 (CHECK)	Model 6 (TEST)	Model 7 (ROUTINE)	Model 8 (SOLVE)	Model 9 (EXPLORE)
School-level	Coef. (Std.)	Coef. (Std.)	Coef. (Std.)	Coef. (Std.)	Coef. (Std.)
INTERCEPT	457.4 (8.7) ***	467.7 (7.3) ***	468.5 (8.7) ***		
Location					
Rural	15.5 (3.3)	18.3 (9.9)	17.7 (10.1)	17.3 (9.5)	18.3 (9.6)
Suburb	13.9 (8.6)	11.9 (8.9)	15.5 (9.0)	16.4 (8.5)	12.6 (8.6)
Locmiss	-24.0 (10.3) *	11.9 (10.4) *	-24.2 (10.6) *	-22.9 (10.0) *	-23.7 (10.1) *
CHECK	15.3 (3.3) ***				
TEST		14.7 (3.4) ***			
ROUTINE			11.2 (3.3) **		
SOLVE				20.1 (3.5) ***	
EXPLORE					18.4 (3.3) ***
Student-level					
CALCLASS					
Girl	-5.7 (2.3) *	-5.7 (2.3) *	-5.7 (2.3) *	-5.7 (2.3) *	-5.7 (2.3) *
Tmjuku	-8.1 (1.5) ****	-8.1 (1.5) ***	-8.1 (1.5) ***	-8.1 (1.5) ***	-8.1 (1.5) ***
SED	5.3 (0.5) ****	5.3 (0.5) ***	5.3 (0.5) ***	5.3 (0.5) ***	5.3 (0.5) ***
LIKEMATH	16.9 (1.2) ****	16.9 (1.2) ***	16.9 (1.2) ***	16.9 (1.2) ***	16.9 (1.2) ***
Level-1 Variance	3919.3	3919.5	3919.3	3918.9	3919.2
Level 2 Variance	1833.7	1863.6	1953.3	1721.2	1744.1

Note. Standard Errors are reported in parentheses.

*$p < .05$

**$p < .01$

***$p < .001$

****$p < .0001$

Table 5b

Results of Hierarchical Linear Model Analysis of

Student Performance and Teachers' Reports on Ways in Which Calculators Are Used -- Portugal

Portugal	**Model 5 (CHECK)**	**Model 6 (TEST)**	**Model 7 (ROUTINE)**	**Model 8 (SOLVE)**	**Model 9 (EXPLORE)**
School-level	Coef. (Std.)	Coef. (Std.)	Coef. (Std.)	Coef. (Std.)	Coef. (Std.)
INTERCEPT	458.4 (7.1) ***	452.9 (4.4) ***	455.2 (5.3) ***	456.3 (5.2) ***	452.0 (4.7) ***
Location					
Rural	-11.9 (8.0)	-11.1 (8.0)	-11.8 (8.0)	-11.9 (8.1)	-12.6 (2.1)
Suburb	-3.3 (5.5)	-2.2 (5.5)	-2.9 (5.5)	-3.0 (5.6)	-1.8 (5.6)
Locmiss	1.7 (9.4)	0.3 (9.5(	1.6 (9.4)	1.6 (9.4)	1.6 (9.4)
CHECK	-1.0 (2.1)				
TEST		2.1 (2.2)			
ROUTINE			0.4 (2.1)		
SOLVE				-0.2 (2.1)	
EXPLORE					2.2 (2.1)
Student-level					
CALCLASS					
Girl	-11.7 (2.5) ***	-11.7 (2.5) ***	-11.7 (2.5) ***	-11.7 (2.5) ***	-11.7 (2.5) ***
Tmjuku	-11.0 (1.8) ***	-11.0 (1.8) ***	-11.0 (1.8) ***	-11.0 (1.8) ***	-11.0 (1.8) ***
SED	2.9 (0.5) ***	2.9 (0.5) ***	2.9 (0.5) ***	2.9 (0.5) ***	2.9 (0.5) ***
LIKEMATH	17.0 (1.3) ***	17.0 (1.3) ***	17.0 (1.3) ***	17.0 (1.3) ***	17.0 (1.3) ***
Level-1 Variance	2966.2	2966.0	2966.1	2966.1	2966.2
Level 2 Variance	539.8	536.8	541.1	541.4	534.7

Note. Standard Errors are reported in parentheses.

*$p < .05$

**$p < .01$

***$p < .001$

Table 5c

Results of Hierarchical Linear Model Analysis of

Student Performance and Teachers' Reports on Ways in Which Calculators Are Used -- Japan

Japan	**Model 5 (CHECK)**	**Model 6 (TEST)**	**Model 7 (ROUTINE)**	**Model 8 (SOLVE)**	**Model 9 (EXPLORE)**
School-level	Coef. (Std.)	Coef. (Std.)	Coef. (Std.)	Coef. (Std.)	Coef. (Std.)
INTERCEPT	599.7 ***	599.6 (4.3) ***	599.7 (4.4) ***	599.3 (4.4)	599.5 (4.4) ***
Location					
Rural	-4.0 (7.0)	-4.2 (7.0)	-4.2 (7.)	-4.0 (7.0)	-4.2 (7.0)
Suburb	11.1 (5.8) *	11.3 (5.9) *	11.0 (5.8)	10.8 (5.8)	11.0 (5.9)
Locmiss	20.3 (32.7)	20.4 (32.6)	20.3 (32.7)	20.2 (32.7)	20.2 (32.7)
CHECK	-4.0 (7.0)				
TEST		-19.9 (7.1) **			
ROUTINE			-1.0 (6.7)		
SOLVE				2.5 (7.6)	
EXPLORE					0.0 (5.3)
Student-level					
CALCLASS					
Girl	1.1 (2.8)	1.1 (2.8)	1.1 (2.8)	1.1 (2.8)	1.0 (2.8)
Tmjuku	-3.4 (1.4)	-3.4 (1.4) *	-3.4 (1.4) *	-3.4 (1.4) *	-3.4 (1.4) *
SED	6.0 (0.6) ***	6.0 (0.6) ***	6.0 (0.6) ***	6.0 (0.6) ***	6.0 (0.6) ***
LIKEMATH	32.3 (1.9) ***	32.4 (1.9) ***	32.3 (1.9) ***	32.3 (1.9) ***	32.3 (1.9) ***
Level-1 Variance	8263.2	8263.5	8263.4	8263.5	8263.4
Level 2 Variance	629.7	627.3	629.9	629.0	630.0

Note. Standard Errors are reported in parentheses.

*p < .05

**p < .01

***p < .001

Appendix A: HLM Specification

NOTE 1: Sample Weight in HLM analysis

"At level-1 (student level) cases should be weighted by the 'normalized' inverse of the student's selection probability given school is selected. In TIMSS, this can be obtained by first calculate the SUBTOTWT for student j of school i as following:

SUBTOTWTij=TOTWGTij/SCHWGTi

and then 'normalize' it to get the weight variable SUBRELWT:

SUBRELWTij=SUBTOTWTij/sum (of SUBTOTWTij)/ni

here ni is the number of students selected in school i. SUBRELWT should be used at level-1. But don't let HLM 'normalize' it since it has been normalized whithin each school.

At level-2 (school level) cases should be weighted by the 'normalized" school weights. For TIMSS, simple use weight SCHWGT and let HLM normalize it."

(FROM a hand-out provided in TIMSS seminar held in Maryland, November 1998, with a note "reference: D. Pfeffermann et al. To appear: JRSS(B?) 1998)

NOTE 2: CENTERING

HLM program is set such that all level-1 variables will be centered around the sample grand mean when they are actually regressed against the outcome variable. This gives the intercept a substantive meaning for interpretation (Bryk & Raudenbush, 1992, p.25).

NOTE 3: Problem of LEVELS

In this application, level-2 are classroom, as well as schools. Ideally, we would like to have students at level-1, classrooms at level-2, and schools at level-3; however, only one classroom in Japan and Portugal and two classrooms in the US are surveyed. Technically, one needs at least (n of predictors + 1) cases at each group unit in HLM. Because the number of classroom in each school is too small, we decided not to consider classrooms as distinct level and treat classrooms and schools at the same level-2. Another problem in this format was the situation where Japanese and Portugal students are rightly considered to be nested within one classroom, but American students are nested within two classrooms. To represent American teachers' calculator use at school level, I used the average of two classrooms sampled. Otherwise, the variable concerning teachers' calculator use will go to different levels for American sample and for Japanese and Portugal samples, making our interpretation difficult. We admit our "cheating levels" and consider it as our weakness, although any HLM application of TIMSS will face the same sets of such decisions.

NOTE 4: Intraclass correlation

Intraclass correlation tells us what proportion of variance is at level-1 and level-2. It is acquired by dividing the variance that comes from one level by the total variance (i.e., level-1variance/level-1variance+level-2 variance, or level-2 variance/level-1variance+level-2 variance). Variance is not an easy statistical construct to compare across countries because it may have different shapes; however, we believe that the difference between US and the other two appear substantial enough.

NOTE 5: Comparison of Variance across models

HLM model decomposes the total variance into level-1 variance and level-2 variance. Level-1 variance of one model is comparable to level-1 variance of another model only when both models have the same level-2 predictors. Likewise, level-2 variance of one model is only comparable to level-2 variance of another model when both models have the same level-1 specifications. For example, one cannot compare the level-1 variance of Model1 and Model2 because level-2 specification of these models are different. Level-2 variance is comparable between Model-1 and Model-2 because level-1 specification of these models are the same.

Appendix B: Variables

KEY VARIABLES:

Dependent variable

Mathscore: five plausible values, BSMPVO1-05 in TIMSS acronym.

Independent variable

LEVEL-1 (student level)

CALCLAS: student-reported use of calculator, 0=never, 1=once in a while, 2=pretty often, 3=almost always.

LEVEL-2 (teacher/classroom/school level)

"How often do students in your mathematics class use calculators for the following activities? Range: 0=never or almost never, 1=some lessons, 2=most lessons, 3=every lesson.

CHECK: Checking answers.

TESTO: Tests and exams.

ROUT: Routine computation.

SOLV: Solving complex problems.

EXPL: Exploring number concepts.

CONTROL VARIABLES:

LEVEL-1 (student level)

GIRL : a dummy variable of 1 if student are female and 0 if male.

TMJUKU : the amount of time that students take extra lessons before or after schools. 0=no time, 1=less than 1 hour, 2=1 to 2 hours, 3=3 to 4 hours, 4=more than 4 hours.

SED: the maximum level of education students are hopeing to complete. 0=I don't know, 1=finish elementary school, 2=finish some high school, 3=some vocational/technical education after high school, 4=some community college, college, or university courses, 5=complete a bachelor's degree at a college or university.

LEVEL-2 (teacher/classroom/school level)

RURAL: schools located in rural or isolated areas,

A dummy variable of 1 if yes, else 0.

URBAN: schools located in rural or isolated areas.

A dummy variable of 1 if yes, else 0.

SUBURB:schools located in rural or isolated areas.

A dummy variable of 1 if yes, else 0.

LOCMISS: schools whose location is missing.

A dummy variable of 1 if yes, else 0.

Appendix C: Level 1 and 2 Descriptive Statistics

USA

LEVEL-1 DESCRIPTIVE STATISTICS

VARIABLE NAME	N	MEAN	SD	MINIMUM	MAXIMUM
BSMPV01	7087	490.88	92.22	172.03	816.67
BSMPV02	7087	490.68	92.37	172.36	816.31
BSMPV03	7087	490.72	92.22	168.23	815.69
BSMPV04	7087	491.11	92.59	167.82	816.09
BSMPV05	7087	490.60	92.94	167.23	816.98
CALCHOME	6985	0.98	0.15	0.00	1.00
CALCLASS	6892	3.02	1.03	1.00	4.00
DGIRL	7087	0.50	0.50	0.00	1.00
TMJUKU	6762	0.45	0.74	0.00	4.00
SED	6682	4.13	2.29	0.00	6.00
LIKEMTH	6923	2.83	0.93	1.00	4.00

LEVEL-2 DESCRIPTIVE STATISTICS

VARIABLE NAME	N	MEAN	SD	MINIMUM	MAXIMUM
CHECK	181	2.09	1.07	0.00	3.00
TEST	181	1.47	1.06	0.00	3.00
ROUT	181	1.98	1.09	0.00	3.00
SOLV	181	2.12	0.98	0.00	3.00
EXPL	181	1.74	1.03	0.00	3.00
SCHWGT	181	1.00	2.60	0.00	31.29
RURAL	181	0.17	0.38	0.00	1.00
SUBURB	181	0.25	0.43	0.00	1.00
URBAN	181	0.43	0.50	0.00	1.00
LOCMISS	181	0.15	0.36	0.00	1.00

PORTUGAL

LEVEL-1 DESCRIPTIVE STATISTICS

VARIABLE NAME	N	MEAN	SD	MINIMUM	MAXIMUM
BSMPV01	3391	455.14	64.56	261.59	671.89
BSMPV02	3391	455.25	63.11	227.58	671.68
BSMPV03	3391	455.19	63.94	228.03	671.32
BSMPV04	3391	455.91	63.55	230.90	671.55
BSMPV05	3391	454.92	63.59	227.24	672.10
CALCHOME	3374	0.99	0.08	0.00	1.00
CALCLASS	3357	3.02	0.86	1.00	4.00
DGIRL	3391	0.49	0.50	0.00	1.00
TMJUKU	3132	0.49	0.81	0.00	4.00
SED	2886	3.69	2.23	0.00	6.00
LIKEMTH	3366	2.79	0.85	1.00	4.00

LEVEL-2 DESCRIPTIVE STATISTICS

VARIABLE NAME	N	MEAN	SD	MINIMUM	MAXIMUM
CHECK	142	2.37	0.87	0.00	3.00
TEST	142	1.42	1.07	0.00	3.00
ROUT	142	2.12	1.13	0.00	3.00
SOLV	142	1.88	1.11	0.00	3.00
EXPL	142	1.66	1.12	0.00	3.00
SCHWGT	142	1.00	0.77	0.30	6.36
RURAL	142	0.09	0.29	0.00	1.00
SUBURB	142	0.25	0.44	0.00	1.00
URBAN	142	0.59	0.49	0.00	1.00
LOCMISS	142	0.06	0.24	0.00	1.00

JAPAN
LEVEL-1 DESCRIPTIVE STATISTICS

VARIABLE NAME	N	MEAN	SD	MINIMUM	MAXIMUM
BSMPV01	5141	603.16	101.74	244.70	891.33
BSMPV02	5141	603.37	101.18	244.95	954.29
BSMPV03	5141	604.12	101.83	240.22	953.41
BSMPV04	5141	604.25	102.67	239.89	953.99
BSMPV05	5141	604.46	100.96	239.46	955.19
CALCLASS	5107	1.29	0.54	1.00	4.00
DGIRL	5141	0.49	0.50	0.00	1.00
TMJUKU	5096	1.28	1.09	0.00	4.00
SED	5091	3.79	2.42	0.00	6.00
LIKEMTH	5095	2.52	0.81	1.00	4.00

LEVEL-2 DESCRIPTIVE STATISTICS

VARIABLE NAME	N	MEAN	SD	MINIMUM	MAXIMUM
CHECK	151	0.04	0.23	0.00	2.00
TEST	151	0.01	0.08	0.00	1.00
ROUT	151	0.12	0.38	0.00	2.00
SOLV	151	0.10	0.33	0.00	2.00
EXPL	151	0.14	0.48	0.00	3.00
SCHWGT	151	1.00	0.58	0.63	3.57
RURAL	151	0.21	0.41	0.00	1.00
SUBURB	151	0.42	0.49	0.00	1.00
URBAN	151	0.36	0.48	0.00	1.00
LOCMISS	151	0.01	0.08	0.00	1.00